3.0 Numeric Targets

Pursuant to federal TMDL requirements, quantifiable and measurable numeric targets that will ensure compliance with water quality standards (beneficial uses, water quality objectives and the state's antidegradation policy) must be established in each TMDL (USEPA 1999).

Big Bear Lake was placed on the Clean Water Act Section 303(d) list primarily due to impairment of the lake's warm and coldwater habitat (WARM and COLD) and wildlife habitat (WILD). However, the lake's water contact and non- contact water recreation (REC1 and REC2) beneficial uses are also impaired. As described in Section 2.0, the impairment results from the high levels of nutrient input and resultant overabundance of noxious aquatic macrophytes (e.g., Eurasian watermilfoil). The TMDLs and numeric targets for Big Bear Lake must be structured to guarantee protection of the COLD, WARM, WILD, REC1, and REC2 beneficial uses and attainment of the nutrient related water quality objectives specified in the Basin Plan (see Section 2.1). In addition, the TMDLs and numeric targets must ensure protection of Bear Creek, downstream of the lake.

3.1 Big Bear Lake Nutrient Numeric Targets

Both total phosphorus and total nitrogen are needed for the growth of macrophytes and algae in Big Bear Lake, and both must be controlled to ensure protection of the lake. Each of these constituents has been shown to be the limiting nutrient for algae growth in the lake under different conditions. Siegfried et al. (1978, 37) reported that phosphorus limited phytoplankton productivity in spring in Big Bear Lake, while nitrogen was the limiting nutrient from July through September. Siegfried and Herrgesell (1979b, 28) reported that phosphorus was the limiting nutrient in spring and also in July in the epilimnion[23]. Nitrogen was found to be the limiting nutrient in July in the hypolimnetic waters, corresponding with release of phosphorus from the sediments (28). Recent water column data (2001-2003) indicate that phosphorus is the limiting nutrient. Interim and final numeric targets for total phosphorus are proposed; a final target for total nitrogen is also recommended. These targets are shown in Table 3-1.

In addition, numeric targets are proposed for chlorophyll *a,* macrophyte coverage and the percentage of nuisance aquatic vascular[24] plant species in the lake. These response parameters are direct indicators of the status of impairment in the lake due to excessive plant growth (and the development of a monoculture by watermilfoil). Monitoring of these parameters will allow tracking of the recovery of the lake from its eutrophic status. These proposed targets are also shown in Table 3-1.

Based on the expected efficacy of programs currently being implemented by BBMWD to improve lake water quality, staff believes that the proposed interim targets can be achieved by 2010 (Table 3-1). Additional investigation of attainability and the water quality measures needed to achieve the proposed final numeric targets (particularly for total nitrogen – see discussion below), will be necessary. Accordingly, staff recommends that an extended schedule for compliance with the final targets be specified. As shown in Table 3-1, staff recommends that compliance with these targets be achieved as soon as possible but no later than 2015.

[23] The epilimnion is the uppermost, warmest, well-mixed layer of a lake during summertime thermal stratification (Holdren, Jones and Taggart 2001, 374).
[24] Vascular plants are a group of plants, including macrophytes, that have specialized cells for conveying fluids within their tissues.

Table 3-1. Proposed numeric targets and indicators for the Big Bear Lake nutrient TMDL

Indicator	Target Value[c]	Reference
Total P concentration (interim)[a]	Annual average[d] no greater than 35 µg/L; to be attained no later than 2010	25th percentile of Big Bear Lake monitoring data from June 2001-April 2002
Total P concentration (final)[a]	Annual average[d] no greater than 20 µg/L; to be attained no later than 2015	Novotny and Olem 1994, 784; Carlson and Simpson 1996, as cited in USEPA, 2000b
Total N concentration (final)[a]	Annual average[d] no greater than 1000 µg/L; to be attained no later than 2015	25th percentile of Big Bear Lake monitoring data from June 2001-April 2002
Macrophyte Coverage[b]	30-60% on a total area basis by 2015 [e]	Leidy 2003b
Percentage of Nuisance Aquatic Vascular Plant Species (final)[b]	95% eradication on a total area basis of Eurasian Watermilfoil and any other invasive aquatic plant species; to be attained no later than 2015 [e]	Petr 2000, 23
Chlorophyll *a* concentration (interim)[b]	Growing season[f] average no greater than 10 µg/L; to be attained no later than 2010	25th percentile of Big Bear Lake monitoring data from June 2001-Oct 2001
Chlorophyll *a* concentration (final)[b]	Growing season[f] average no greater than 5.0 µg/L; to be attained no later than 2015	Carlson and Simpson 1996, as cited in USEPA 2000b

[a] source targets related to load allocations/waste load allocations (see Section 5.0)
[b] monitoring targets that will not be used for load allocations/waste load allocations
[c] compliance with the targets to be achieved as soon as possible, but no later than the date specified
[d] Annual average determined by the following methodology: the nutrient data from both the photic composite and discrete bottom samples are averaged by station number and time; a calendar year average is obtained for each sampling location; and finally, the separate annual averages for each location are averaged to determine the lake-wide average. The open-water sampling locations used to determine the annual average are MWDL1, MWDL2, MWDL6, and MWDL9.
[e]To be calculated as a 5-yr running average based on measurements taken at peak macrophyte growth as determined in the Aquatic Management Plan (see Attachment A –Task 8).
[f]Defined as the period from May 1-October 31

No wasteload or load allocations would be derived from the targets for the response indicators (chlorophyll *a*, macrophyte coverage and percentage of nuisance aquatic vascular plant species). This is because the correlation between nutrient loads and macrophyte coverage or biomass are obscure and chlorophyll *a* concentrations cannot be predicted from total phosphorus. For example, a log-log plot of chlorophyll *a* and total phosphorus showed little correlation ($R^2 = 0.37$) (Figure 3-1). Complex nutrient dynamics, including the fact that rooted aquatic vascular plants obtain nutrients from both the sediment and the water column, complicate the evaluation of any such correlations. However, further research in this area might provide some means of predicting macrophyte biomass or coverage from nutrient loads (USEPA 2000b).

Board staff recognizes that much more information on the nature and extent of beneficial use impairment by macrophytes is needed to refine the targets. For example, the effects of increased/decreased macrophyte coverage and a more diverse macrophyte habitat on the growth of macroinvertebrates, zooplankton, phytoplankton, as well as fisheries habitat, need to be explored. The proposed targets are based on protecting the aquatic life and recreational beneficial uses of the lake. If the total phosphorus and nitrogen targets are met while the other targets are not, or vice versa, the numeric targets will be re-evaluated and revised accordingly. A phased TMDL approach is recommended to conduct further appropriate investigations and to review and revise the TMDLs as necessary.

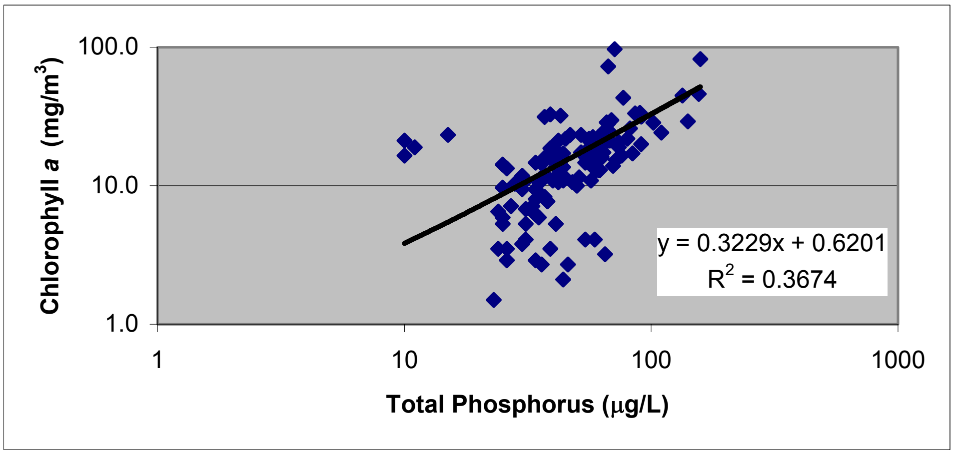


Figure 3-1: Chlorophyll *a* as a function of total phosphorus (Data from 2001-2003)

To establish the numeric targets, Regional Board staff first considered the use of established numeric nutrient objectives. As discussed in Section 2.1, the Basin Plan specifies numeric water quality objectives for both phosphorus and nitrogen for Big Bear Lake. The total phosphorus objective of 150 μg/L and the total inorganic nitrogen (TIN) objective of 150 μg/L were established in the 1975 Basin Plan based on the data then available. However, according to the National Eutrophication Survey (Novotny and Olem 1994, 784), total phosphorus values of <10 μg/L are indicative of oligotrophic conditions; mesotrophic conditions are observed at 10-20 μg/L of total phosphorus; and eutrophic conditions are observed with total phosphorus concentrations >20 μg/L. Clearly, based on these values, the present numerical water quality objective of 150 μg/L of total phosphorus allows for hypereutrophic conditions. Similarly, it appears likely that the established total inorganic nitrogen objective is not protective of beneficial uses. Although inorganic nitrogen is the bioavailable form of nitrogen, organic forms of nitrogen can be transformed into a bioavailable form (note: organic nitrogen comprises over 90% of the total nitrogen in Big Bear Lake for data collected in 2001-2003). Therefore, it is essential to control the total amount of nitrogen, not just the inorganic forms. It appears that revised nitrogen and phosphorus objectives need to be developed and considered[25]. If and when such objectives are incorporated in the Basin Plan, it would be appropriate to apply them in the

[25] It may be appropriate to consider numeric or narrative objectives specific to Big Bear Lake for chlorophyll *a*, macrophyte coverage and/or species diversity, rather than or in addition to numeric objectives for phosphorus and nitrogen, given (1) the significant uncertainties that exist regarding the dynamics of these nutrients in the lake; (2) concerns regarding the attainability of target phosphorus and nitrogen concentrations (see further discussion in this section); and, perhaps most importantly, (3) the direct nature of the evidence of impairment that is provided by these parameters. The proposed implementation plan (Task 10) reflects this consideration.

selection of revised numeric targets and refinement of the TMDLs. Development of these objectives is identified as a part of the Implementation Plan for these TMDLs (see Section 9.1, Implementation Recommendations).

Until appropriate revised objectives are established, alternative methods of identifying numeric targets must be used. Regional Board staff evaluated other alternatives to select both water quality indicators and target values. USEPA recommends the following approaches for states in developing nutrient criteria, listed in order of preference: 1) Develop nutrient criteria based on localized conditions and protection of designated beneficial uses using the process described in EPA's Technical Guidance Manuals for nutrient criteria development; 2) Adopt EPA's section 304(a) water quality criteria (i.e., EPA's recommended nutrient Ecoregion values); 3) Use other scientifically defensible methods to develop nutrient criteria protective of designated uses (USEPA 2000a). USEPA recognized that developing nutrient criteria on a lake-by-lake or stream-by-stream basis would be expensive and time consuming. Therefore, USEPA developed recommended reference values for different types of bodies of water for each ecoregion. USEPA stressed the need to use both causal (total phosphorus and total nitrogen) and response (e.g., algal chlorophyll and some form of water clarity, i.e., turbidity or Secchi depth) indicators for lakes/reservoirs and rivers/streams. States can then either adopt the Section 304(a) water quality criteria for nutrients or use the recommended ecoregion values as guidance in developing their own nutrient criteria.

The proposed numeric targets for the Big Bear Lake TMDL were developed based on USEPA's recommended options 1 and 3. Because Big Bear Lake is not in a pristine condition and most likely will always remain in a mesotrophic to eutrophic status (Leidy 2003a) (Section 2.0), the recommended Nutrient Ecoregion II[26] values (shown in Table 3-2) were not used for either the proposed interim or final numeric targets, as these values apply to lakes that are minimally impacted by human activity. The interim numeric targets for the Big Bear Lake nutrient TMDLs were developed based on USEPA's Nutrient Criteria Technical Guidance Manual for lakes and reservoirs (USEPA 2000b). In developing nutrient criteria, data are collected from so-called reference conditions and some percentile (e.g., lower or upper 25th percentile of the dataset) is chosen to be the criterion. However, when, as is the case for Big Bear Lake, there are no ideal reference conditions, then the conditions observed presently serve as the reference conditions and the criterion chosen should be based on a lower percentile (i.e., the 25th percentile) of data (USEPA 2000b). As discussed in more detail below, the 25th percentile of data collected from 2001-2002 was used to calculate the recommended interim numeric total phosphorus and chlorophyll a targets and final total nitrogen numeric target. The proposed final total phosphorus and chlorophyll *a* numeric targets for the Big Bear Lake nutrient TMDLs were developed using the third approach recommended by USEPA. Specifically, a trophic index system (see Appendix C) was used to derive the final numeric targets needed to move Big Bear Lake from eutrophic to mesotrophic status.

[26] Nutrient Ecoregion II includes the mountainous areas of 11 states (Washington, Oregon, California, Idaho, Montana, Wyoming, New Mexico, Colorado, Utah, Arizona, South Dakota). Data sets from Legacy STORET, and EPA Region 10 were used to assess nutrient conditions from 1990 to 1999, with most of the data obtained from Oregon, Washington, Colorado, and Utah. No data were obtained for the Southern California Mountains subecoregion within Ecoregion II for lakes (USEPA 2000a).

Table 3-2. EPA's recommended nutrient criteria for Ecoregion II in µg/L

Indicator	Recommended Value for Lakes Ecoregion II
Total Phosphorus	8.8
Total Nitrogen	100
Chlorophyll *a*	1.9
Secchi (meters)	4.5

Source: USEPA 2000a

Derivation of the proposed targets for Big Bear Lake is discussed in more detail below.

3.1.1 Phosphorus and Nitrogen

Numeric Targets

The proposed interim target for total phosphorus is 35 µg/L[27] as the annual average concentration of both the photic composite and bottom discrete samples at the four main TMDL lake monitoring stations (MWDL1, MWDL2, MWDL6, and MWDL9). This number represents the 25th percentile of the total phosphorus concentrations during the monitoring period from June 2001- April 2002 (see Appendix B-Minitab results). This time period is identified as a reference state since the application of an aquatic herbicide, Sonar, took place after this time (in May 2002). There is no proposed interim nitrogen target (see Section 5.1 for further discussion of nitrogen numeric targets); an annual average of 1000 µg/L[28] is the proposed final nitrogen numeric target (see Appendix B-Minitab results).

The proposed final target for total phosphorus is 20 µg/L as the annual average concentration of both the photic composite and bottom discrete samples at the four main TMDL lake monitoring stations (MWDL1, MWDL2, MWDL6, and MWDL9). This value is the concentration that the USEPA considers as the dividing point between mesotrophic and eutrophic conditions (Novotny and Olem 1994, 784). A value of 20 µg/L will produce a Trophic Status Index (TSI) of 47 (see Appendix C), which is on the high end of the mesotrophic level (Carlson and Simpson 1996, as cited in USEPA 2000b). If a TN/TP ratio of 10:1 (assuming phosphorus limitation) and the value of 20 µg/L for total P were used, then the corresponding total N target value would be 200 µg/L. However, it appears that this value is too stringent for Big Bear Lake and could not be met. WASP model results (discussed in Section 5.1) support this contention. Therefore, the proposed final target for total nitrogen is 1000 µg/L as the annual average concentration of both the photic composite and bottom discrete samples at the four main TMDL lake monitoring stations (MWDL1, MWDL2, MWDL6, and MWDL9). Even if the total nitrogen target is set at this level, no WASP model simulations of nutrient control measures

[27] The 25th percentile calculates to 31 µg/L. Given uncertainties in the data, this value was simply rounded up to 35 µg/L for the purposes of these TMDLs.
[28] The 25th percentile calculates to 990 µg/L. Given uncertainties in the data, this value was simply rounded up to 1000 µg/L for the purposes of these TMDLs.

results in compliance. As discussed in Section 5.1, staff believes that this is at least partially due to the limitations of the WASP model. However, further investigations of the propriety and attainability of this recommended target are clearly necessary. Again, this supports the recommendations for a phased TMDL approach and extended schedule for compliance with the final numeric targets.

3.1.2 Macrophyte Coverage

According to the most recent data, collected by ReMetrix, Inc. in July 2000, there were approximately 781 surface acres of submersed vegetation in Big Bear Lake (ReMetrix 2001, 4). At that time, the lake had an elevation of approximately 6738 feet (obtained from the BBMWD's website), corresponding to a water surface area of 2,569 acres (Tetra Tech 2004b). Based on these data, approximately 29% of the surface area of the lake was covered with submersed aquatic vegetation. BBMWD reported (2002a) that the predominant species is Eurasion milfoil (~ 73%), followed by coontail (~20%) and other species (~7%). BBMWD is able to control approximately 240 acres (31%) of the aquatic plant growth by harvesting. About 86% of the aquatic plant harvesting occurs around private docks, and the other 14% occurs where navigational hazards need to be removed or where public access needs to be improved. Harvesting of the Eurasian watermilfoil is not a preferred control because it can spread Eurasian watermilfoil fragments to other areas of the lake and can impact the bottom biota (Madsen 2000).

Numeric Target

The proposed numeric target is specified as a range of 30-60 percent macrophyte coverage on a total lake basis. Recent findings (Leidy 2003b) suggest that approximately 60 percent of the reservoir bottom can support coverage of rooted aquatic macrophytes in Big Bear Lake. Provided that the macrophyte community is diverse, there is no reason to reduce this level of coverage. However, macrophyte reductions may be necessary to prevent dominance of nuisance/noxious species. Reducing macrophyte coverage below 60% will always require maintenance. Leidy (2003b) does not recommend reducing the macrophyte coverage to less than 30 percent in order to maintain a balanced composition of aquatic fauna within the lake. Furthermore, Leidy (2003b) states that an even distribution of aquatic plants within the perimeter of the lake is also desirable. Studies conducted on the optimal percentage of macrophyte coverage from a fisheries perspective have shown that aquatic plant coverage can range from 20-36% on a total area basis and that in eutrophic lakes, aquatic plant coverage in the littoral zone should range from 20-40% (Schneider 2000). It is known that aquatic macrophytes are necessary if a healthy fishery is to be maintained. When future studies are conducted to establish the link between macrophyte coverage and a healthy fishery in Big Bear Lake, the proposed numeric target for macrophyte coverage will be reviewed and revised accordingly.

3.1.3 Percentage of Nuisance Species

Eurasian watermilfoil and coontail proliferate in Big Bear Lake due to the excessive levels of nutrients in the lake (see Section 2.2). Reduction and/or the eradication of Eurasian watermilfoil will allow a more diverse plant community to flourish, which in turn will improve fisheries and other wildlife habitat. Petr (2000, 23) states that native plants provide better habitat for aquatic invertebrates than does Eurasian watermilfoil.

Reducing nutrient loading should result in the control of Eurasian watermilfoil, coontail and other invasive aquatic vascular plant species. However, this will need to be supplemented with spot treatments of herbicide, hand pulling of weeds, and other methods of eradication that might be identified. In addition, it will be necessary to educate the public regarding the ways that they can prevent the appearance/reappearance of invasive aquatic plants in the lake. Vessel wash off areas will need to be provided to prevent the introduction of any invasive aquatic plant elsewhere, as well as the reintroduction of these species to the lake.

Reductions in nutrient loading would likely also affect the growth of beneficial species of macrophytes, which are necessary to support the wildlife-related beneficial uses of the lake. A careful balance will need to be struck between nutrient reductions and the need to support some types of macrophyte growth. As suggested above (Section 3.1), it may be that adjustments will need to be made to the numeric targets (and objectives) for phosphorus and nitrogen, the causal indicators, based on demonstrated needs to meet the response indicator targets, which are more indicative of the actual health of the lake and its beneficial uses. This will require integration of nutrient loading considerations with aquatic plant management plans, including dredging activities.

Numeric Targets

The proposed final target, to be achieved as soon as possible but no later than 2015, is a 95% eradication of Eurasian watermilfoil and any other invasive aquatic vascular plant species on a total area basis.

3.1.4 Chlorophyll *a*

Chlorophyll *a* is used as an estimator of algae biomass. Values greater than 10 µg/L are considered to be indicative of eutrophic conditions, while values less than 4 µg/L are representative of oligotrophic status (Novotny and Olem 1994, 784).

Numeric Target

The proposed interim target for chlorophyll *a* is a growing season average of 10 µg/L, based on the photic composite samples at the four main TMDL monitoring stations (MWDL1, MWDL2, MWDL6, and MWDL9) in the water column. This number represents the 25th percentile of the chlorophyll *a* concentration measured during the monitoring period from June 2001- October 2001 (i.e., the growing season). This time period is identified as a reference state since the application of an aquatic heribicide, Sonar, did not take place until May 2002. The target is recommended as a growing season average (May 1 through October 31) since the critical condition for lake water quality effects from algae growth occurs during this time frame.

The proposed final target for chlorophyll *a* is 5.0 µg/L, which corresponds to a TSI of 47 (see Appendix C). This is on the high end of the mesotrophic level (Carlson and Simpson 1996, as cited in USEPA 2000b).

4.0 Source Assessment

Current sources of nutrient loading to Big Bear Lake and its tributaries were evaluated using computer modeling and direct load measurements. The source assessment discussion below describes the sources of nutrients and summarizes the nutrient load estimates. Values from the literature were used in the current Hydrological Simulation Program Fortran (HSPF) model to estimate nutrient loads from the general land use categories. For more detailed information on the watershed modeling and external nutrient source assessment please refer to the nutrient budget report (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003) and to the updated model runs (Hydmet, Inc. 2004). Note that all of the following graphs and tables for the flow and HSPF loads were created by Regional Board staff using data supplied by Hydmet, Inc (2004).

External nonpoint sources are grouped into general land use categories (forest and resort). Point sources include urban runoff from high density urban and residential land use. The urban runoff category represents land uses that are within the City of Big Bear Lake, the County of San Bernardino and Caltrans. The urban discharges from these areas are regulated under NPDES permits issued to the San Bernardino County Flood Control District, the County of San Bernardino and the City of Big Bear Lake, NPDES No. CAS 618036 (Regional Board Order No. R8-2002-0012) and Caltrans, Order No. 99-06-DWQ.

The major categories of sources that were evaluated in the Big Bear Lake watershed were:

- runoff from forest and resort land uses
- runoff from residential and high density urban land uses (combined into the generic term urban runoff)
- atmospheric deposition
- internal nutrient loads from lake bottom sediments
- internal nutrient loads from macrophyte senescence and die-off

Other sources of nitrogen and phosphorus within the Big Bear Lake watershed that were not assessed separately, but instead were lumped into the generic "urban runoff" and that would be expected to contribute nutrient loads include golf courses, parks, runoff from residential and commercial irrigation and fertilization practices, runoff from the trout pond and the zoo, runoff associated with livestock, and septic systems. As part of the phased TMDL approach, these sources should be evaluated and monitored to obtain source-specific nutrient concentrations within this watershed. These values would then be used to rerun the current HSPF model to reassess the proposed numeric targets and wasteload and load allocations.

The HSPF model simulated streamflow, total suspended sediment and nutrients and output was provided by water years. The hydrologic component of the model was calibrated to the limited available data on monthly Big Bear Lake inflow[29] by three independent procedures. These procedures included preparation of a lake water balance, conduct of a Plunge Creek regression and conduct of a Santa Ana River regression. Note that Plunge Creek, although in an adjacent watershed, has similar hydrology to the Big Bear Lake watershed, and the Santa Ana River gaging station located downstream of Big Bear Lake was used to calibrate the outflow at Big Bear Lake. These procedures had to be used to simulate flows since there are currently no gaging stations in the Big Bear Lake

[29] Weirs and flow meters installed in 2002 at key locations within the watershed were used to sample stormwater and record flows. However, much more flow and load data need to be collected before there will be a better understanding of the duration, magnitude and type of flow (e.g., baseflow, storm events or snowmelt) that delivers nutrients to the lake.

watershed and, again, there are few flow data available for the watershed. One of the limitations in using the HSPF model is that the events that were sampled for calibration purposes were of low intensity and consisted of rainfall/snowmelt in dry years. These results could not be extrapolated to average precipitation or wet years. Fits between the simulated and observed flows for calibration purposes were within 10% for annual runoff and 20% for monthly runoff. This was considered sufficient due to the fact that there were few local tributary inflow data, and the only recorded precipitation data records were near the lakeshore, with no records of higher elevation precipitation or snow cover (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003). As part of the phased TMDL approach, additional flow data collected during higher intensity rainfall and snowmelt and data collected from a high elevation weather station (proposed for installation) will be used to calibrate the HSPF watershed model.

The water quality component of the HSPF model simulated total nitrogen, total phosphorus, total kjeldahl nitrogen (TKN), nitrate, nitrite, orthophosphate and ammonia, while the sediment component of the model simulated total suspended sediment. HSPF model calibrations for external nutrient loads based on Big Bear Lake watershed data were not performed since the existing observed data were not adequate for this purpose (BBMWD, Hydmet, Inc., and AquAeTer, Inc., 2003).

Fourteen water years, 1990-2003, were simulated using the HSPF model, though only five of those years, 1999-2003, were used to calculate the TMDLs due to the more limited simulation period of the lake model (i.e., the WASP model)[30]. As discussed in Section 5.0, the WASP lake model was used to determine nutrient load capacity and to evaluate reductions required from external and internal sources. Although some lake water quality data were collected during average and wet years (see Section 2.2), these data, for the most part, were not adequate for the WASP modeling effort because: 1) total phosphorus detection limits were too high and therefore, the majority of samples for total phosphorus were non-detect; 2) inorganic phosphorus and nitrogen detection limits were too high and therefore, the majority of samples for inorganic phosphorus and nitrogen were non-detect; 3) ammonium nitrogen was rarely measured, therefore, inorganic nitrogen determinations were based only on nitrate and nitrite; 4) the WASP model needs inputs of both inorganic and organic phosphorus and nitrogen and the data collected prior to 2001 were not adequate. ***The proposed TMDLs are based on the average of all loads from the period of record of 1999 to 2003. This period only includes loads from dry hydrological conditions.*** This report also presents the average external loads for 1990-2003, a period that incorporates loads from wet, dry, and average hydrological periods, and the loads from 1993, a wet hydrological period. The latter results are presented for comparison purposes only; because of the inability to calibrate the WASP lake model for wet and average hydrologic conditions, these loads were not considered in the development of the recommended TMDLs. The proposed implementation plan includes tasks designed to address this deficiency.

The Watershed Database Management (WDM) file consists of all the meteorological time series data used for the hydrology simulation of the HSPF model and was assembled for the time period of October 1948 to December 2002 (54 years). The WDM file was extended through December 2003 for the WASP modeling effort conducted by Tetra Tech in 2004. Because hourly precipitation data were not available or published for any location in the San Bernardino Mountains before October 1948,

[30] The WASP model required the HSPF output in a different format than that which was delivered to the RWQCB. Staff needed HSPF output corresponding to individual tributaries while WASP required output corresponding to the 10 lake segments used in the WASP model setup (see Section 5). The two model simulations used the same data and .wdm file, but the output of the two runs was provided in two different formats. The WASP model input loads were based on calendar years, while the HSPF output provided to staff was based on water years. Staff used the last three months of 2003 (October, November, and December) from the HSPF output provided for the WASP model to determine loads and flow from the 2003 calendar year.

model simulations prior to 1948 were not possible (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003).

The GIS data used to characterize the Big Bear Lake watershed consisted of subbasins, mean annual precipitation, elevation/aspect, land use, and soils. The datasets contained the following attributes: 1) four land uses (forest, resort, residential, and high density urban); 2) two elevation zones (>7,500 ft and <7,500 ft); 3) two aspects (land oriented facing north or facing south); 4) four precipitation zones (15-20", 20-25", 25-30", and 30-35"); and, 5) two dominant soil types (low and high water holding capacity). By combining the GIS datasets, a total of 128 types of pervious surfaces (PERLND in the HSPF model) were obtained. Ultimately, only 30 pervious land use types were used to define all the possible combinations of the variables. The other combination types simply were not present or had areas that were less than 10 acres. Eight impervious land use types were used in the Big Bear Lake watershed model (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003).

The surface area of the lake was estimated at approximately 2,282 acres. Based on the bathymetry provided by ReMetrix in 2001, the surface area of the lake at full pool (i.e., at a lake elevation of 6,743.2 ft.) was determined to be 2,808 acres, with a corresponding volume of 72,696 af (compare to Table 1-1) (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003). Due to sedimentation, the lake has lost some storage capacity since the original gage height-lake capacity chart was created in 1977. The values cited above, based on the newest bathymetry obtained in 2000, were used in the HSPF model.

Hydrology of the Big Bear Lake Watershed

The summary of HSPF simulated inflows for the period of record 1990 to 2003 around the average total flow shows that 1993 was the wettest year during this period (Figure 4-1). In fact, out of the entire 14-year period, there were only 3 years with flow above the average total flow of 14,032 AF (1993, 1995 and 1998). The majority of the years are below the average total flow. Low-flow conditions typically occur from July through October, with the minimum monthly average simulated flow of 34.7 AF recorded during August (Figure 4-2).

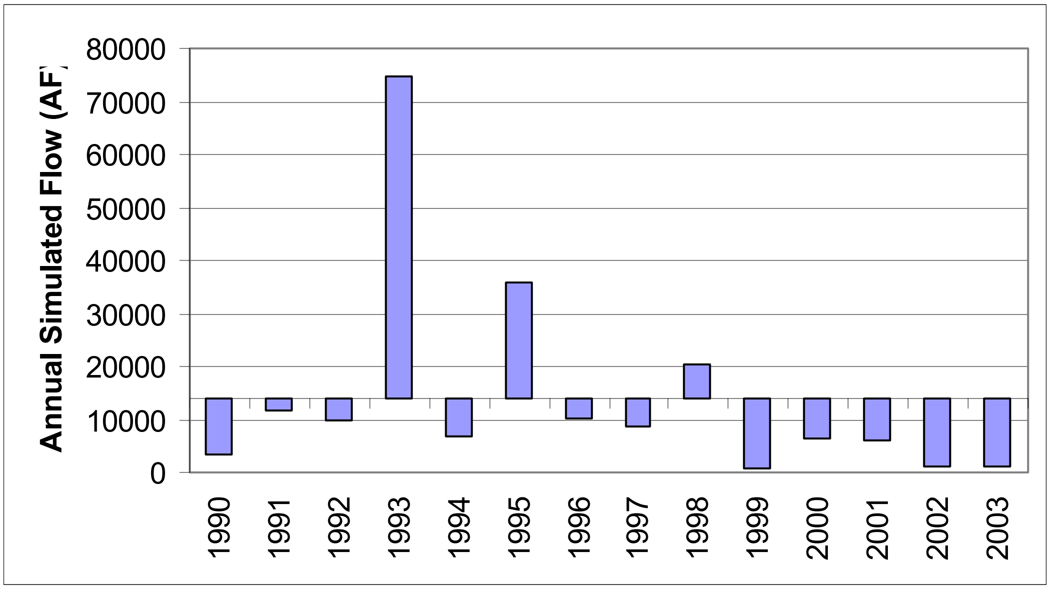


Figure 4-1: Variation of annual total flow from HSPF model land uses around average total flow for the period of record 1990-2003 (CY)

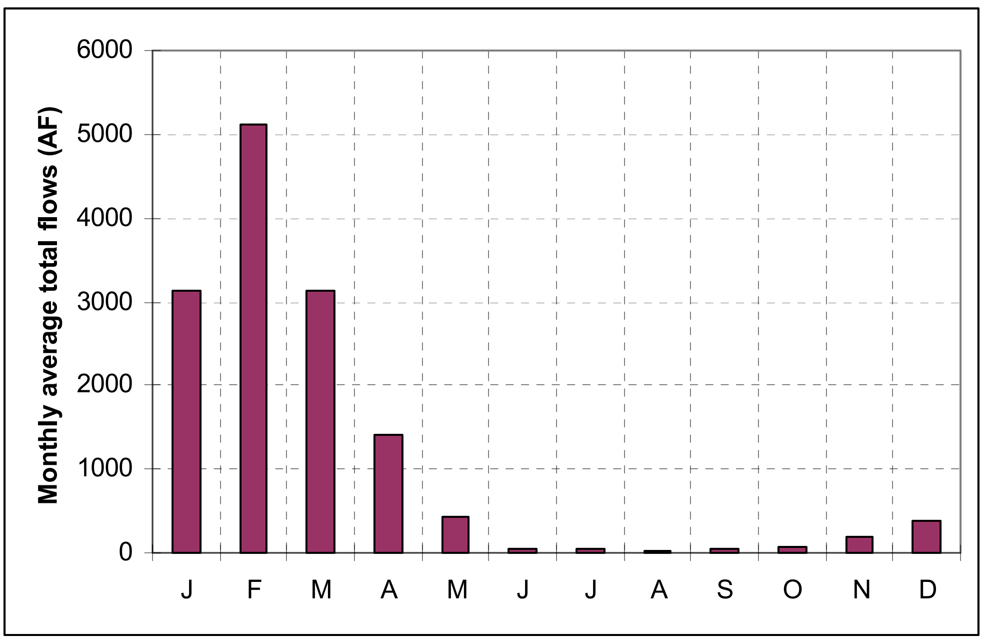


Figure 4-2: Monthly trends of average total flow for Big Bear Lake, 1990-2003 (CY)

4.1 Loads from Forest, Resort and Urban land uses

Nutrient loads in runoff from forest, resort and urban land uses include phosphorus and nitrogen. These water quality constituents were simulated by the PQUAL module section in HSPF using simple relationships with sediment and water yield. Figures 4-3 and 4-4 show nutrient loads from forest, resort and urban land uses during two different periods. The highest total nitrogen loads come from urban land uses (Figure 4-3) while the highest total phosphorus loads come from the forested areas during the period 1990-2003 and from urban land uses during the period 1999-2003 (Figure 4-4). Over 80% of the total nitrogen in Big Bear Lake is associated with the dissolved form. Conversely, most of the phosphorus is associated with the particulate phase (i.e., granitic sand, of which a fraction is the mineral apatite[31]), with the greatest loads from the forested areas during wet hydrological periods.

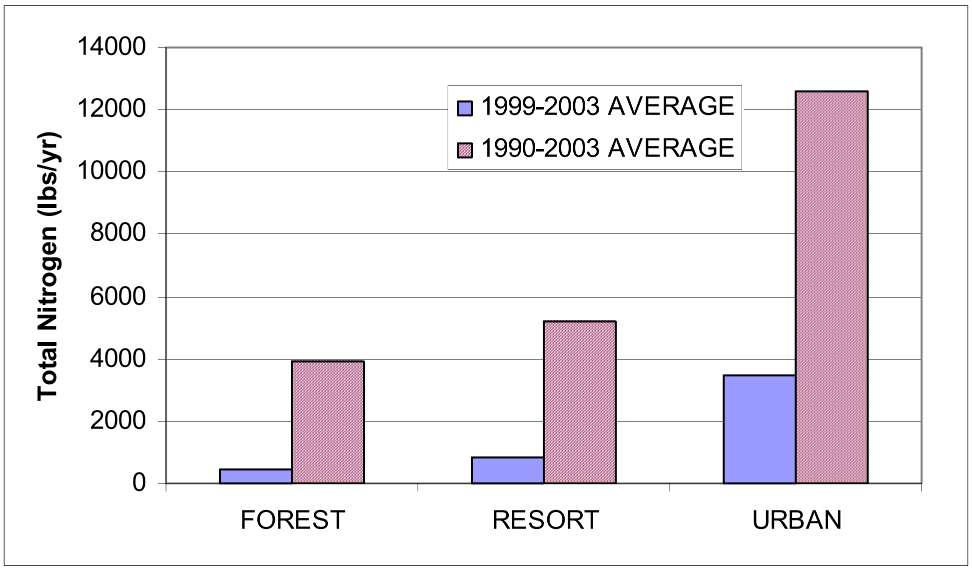


Figure 4-3: Average annual nitrogen loads from land uses for 5 years, 1999-2003, and 14 years, 1990-2003 (CY)

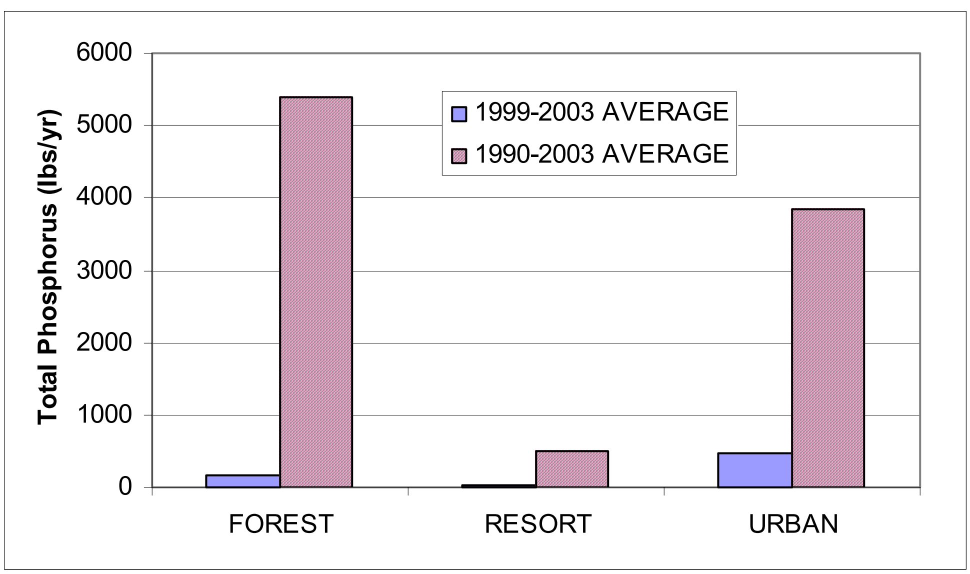


Figure 4-4: Average annual phosphorus loads from land uses for 5 years, 1999-2003, and for 14 years, 1990-2003 (CY)

[31] Apatite is a class of minerals that are insoluble calcium phosphates ($Ca_3(PO4)_2$).

Annual total nitrogen and total phosphorus loads to Big Bear Lake simulated by the HSPF model for 1990 to 2003 are shown in Table 4-1. The largest total nitrogen and phosphorus loads, 130,747 lbs/year and 98,010 lbs/year, respectively, during the last 14 years (1990-2003) were observed in 1993, which corresponded to the wettest year and the greatest external inflows. Total nitrogen and total phosphorus loads for the last 5 years (1999-2003) averaged 4,716 lbs/yr and 683 lbs/yr, respectively (Table 4-1). The annual average loads during the 14-year period, 1990-2003, are more than 4 times the annual average loads for the period of record from 1999-2003. These differences in the annual average loads for these two time spans are attributed to wet hydrological periods that occurred in 1993, 1995, and 1998. It is worth noting that in the case of phosphorus, although wetter years would bring more phosphorus into the system, all of this additional phosphorus might not be readily bioavailable (see discussion in Section 4.3).

Table 4-1. Simulated annual nutrient loads to Big Bear Lake (calendar years)

CALENDAR YEAR	PRECIPITATION AT BIG BEAR LAKE DAM (IN)+	TOTAL ANNNUAL INFLOW (AF)	TOTAL PHOSPHORUS (LBS)	TOTAL NITROGEN (LBS)
1990	22	3271	486	5001
1991	38	11665	1813	18466
1992	44	9677	990	12843
1993	74	74610	98010	130747
1994	32	6852	811	9969
1995	49	35880	19602	49693
1996	41	10262	2357	10925
1997	27	8742	1207	11413
1998	50	20246	7676	30986
1999	13	852	269	2120
2000	25	6254	1910	8365
2001	31	5906	667	8588
2002	15	1104	263	2077
2003	32	1130	308	2429
1999-2003 AVERAGE	**23**	**3049**	**683**	**4716**
1990-2003 AVERAGE	**35**	**14032**	**9741**	**21687**
MAX	74	74610	98010	130747
MIN	13	852	263	2077

+Annual rainfall data are from January 1 through December 31 (*Data Source:* BBMWD 2004b)

Based on the HSPF simulations, on an annual basis for 1999-2003, runoff from forest areas contributed 10% of the total nitrogen load and 26% of the total phosphorus load; runoff from resort areas contributed 17% of the total nitrogen load and 5% of the total phosphorus load; runoff from urban areas contributed 73% of the total nitrogen load and 70% of the total phosphorus load. These loadings are tabulated and summarized in Table 4-2.

Nitrogen from the urban land uses is likely a result of a combination of dryfall[32] and wet atmospheric deposition. Other nitrogen sources from residential and high density urban areas would likely include fertilizers. Dry atmospheric deposits, street deposition, and organic litter would be expected to build up on the impervious land surfaces. Rainfall would wash these sources off into the receiving bodies of water due to the reduced ability of water to infiltrate into the ground. The volume of runoff from the various land surfaces drives the nutrient loads from impervious land surfaces. In HSPF, nutrient loads from pervious land segments move along three paths: overland flow, interflow (i.e., subsurface runoff) and groundwater flow. Most of the phosphorus is associated with the sediment/particulate discharge present when surface runoff occurs, with the most significant contributions from forest land use.

[32] Dryfall is atmospheric deposition of nutrients without accompanying precipitation.

Table 4-2. Total annual simulated nutrient loads from HSPF model land uses for the 14 year period, 1990-2003 (CY)

	TP LOADS FROM LAND USES (LBS/YEAR)				**TN LOADS FROM LAND USES (LBS/YEAR)**			
WATER YEAR*	FOREST	RESORT	URBAN	TOTAL	FOREST	RESORT	URBAN	TOTAL
1990	53	16	416	486	382	876	3743	5001
1991	371	77	1365	1813	2203	4840	11423	18466
1992	226	51	714	990	1717	3374	7752	12843
1993	60325	5057	32628	98010	25478	31504	73764	130747
1994	153	37	621	811	1143	2396	6431	9969
1995	8992	949	9661	19602	11630	11989	26074	49693
1996	1202	189	967	2357	2586	2505	5835	10925
1997	348	67	792	1207	2409	2823	6181	11413
1998	2908	433	4334	7676	4904	8494	17588	30986
1999	3	4	261	269	9	64	2047	2120
2000	741	119	1049	1910	1333	1709	5323	8365
2001	126	33	508	667	936	2157	5495	8588
2002	3	4	256	263	10	64	2003	2077
2003	3	4	301	308	11	62	2356	2429
1999-2003 AVERAGE	**175**	**33**	**475**	**683**	**460**	**811**	**3445**	**4716**
% OF TOTAL AVERAGE	26%	5%	70%		10%	17%	73%	
1990-2003 AVERAGE	5390	503	3848	9741	3911	5204	12572	21687
% OF TOTAL AVERAGE	55%	5%	40%		18%	24%	58%	
MAX	60325	5057	32628	98010	25478	31504	73764	130747
MIN	3	4	256	263	9	62	2003	2077

Note: The 1999-2003 average is included because of the limitations of the WASP model that restricted the modeling to this period (see Section 5.1).

4.2 Atmospheric Deposition

Nutrient inputs from rainfall as well as dryfall may be significant sources of nutrient loads to lakes. Sources of nitrogen air emissions are agriculture (i.e., CAFOs[33]), transportation, and industry. The forest surrounding Big Bear Lake is likely an additional source. Studies indicate that nitrogen saturation in the forested areas in the San Bernardino mountains has likely occurred (Bytnerowicz and Fenn 1996). While undisturbed forests are typically nitrogen poor and tend to assimilate all of the atmospherically deposited nitrogen, forests that are exposed to excessive amounts of atmospheric nitrogen become nitrogen saturated (Bytnerowicz and Fenn 1996). Nitrogen saturation can result in high concentrations of nitrate in local streams that drain nitrogen saturated forests (Fenn and Poth 1999).

No direct precipitation or dryfall samples were collected for Big Bear Lake in recent years, although precipitation samples were collected during the 1970s (Irwin and Lemons 1974, 5-6). Irwin and Lemons (1974, 26-27) estimated that 31,765 lbs of nitrogen and 3,177 lbs of phosphorus entered Big Bear Lake by precipitation in the 1970s. The effects of atmospheric deposition on surface water quality within the Big Bear Lake watershed warrant a more thorough investigation as part of the phased TMDLs.

Direct atmospheric loads to Big Bear Lake were estimated based on values reported in the literature for southern California mountain areas (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003). Literature values for atmospheric deposition ranged from 25 to 35 kg N/ha/yr or 55 to 77 lbs N/ha/year at Camp Paivika in the western San Bernardino Mountains to 3 to 6 kg N/ha/yr or 7 to 13 lbs N/ha/yr at Barton Flats in the eastern San Bernardino Mountains (Fenn and Poth 1999).

Total phosphorus deposition was estimated at one-tenth of the total nitrogen load in the original nutrient budget study (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003). For the WASP model setup (see Section 5.1), Tetra Tech (2004a) stated that this might be an overestimation due to the unusually high total nitrogen deposition in the area. Phosphate deposition is rarely measured and only nitrogen deposition rates were mentioned in the recent literature for the San Bernardino Mountains. Therefore, Tetra Tech did not use the deposition of phosphate in the WASP model setup. Based on the above-mentioned studies, it is estimated that the atmospheric loads to Big Bear Lake range from 5 to 30 kg N/ha/yr, or 11-66 lbs/ha/year. A total nitrogen atmospheric load of 10 kg/ha/yr, or 22 lbs N/ha/yr, was considered reasonable for this study because there is a dry deposition nitrogen gradient running from west to east in the San Bernardino Mountains, with higher values observed at the western end (Bytnerowicz and Fenn 1996). Since Big Bear Lake is located near the eastern end of the San Bernardino mountains, it seemed reasonable to use the values associated with the eastern end sites as opposed to the western end sites. Literature values suggest that total phosphorus output ranges between one-fiftieth and one-twentieth of the total nitrogen deposition rate (Holdren, Jones, and Taggart 2001, 16). The total phosphorus atmospheric load was set at one-twentieth of the total nitrogen load, or 1.1 lbs P/ha/yr. These estimated atmospheric loading rates include both dry and wet deposition. The estimated atmospheric loads for total N and total P under dry conditions (1999-2003) are 21,474 lbs/yr and 1,074 lbs/yr, respectively. The estimated atmospheric loads in a wet year are 23% higher than those in a dry year. It must be emphasized, however, that the loading rates that were used to calculate these estimates are based on limited information and need to be refined with empirical data for both wet and dry conditions.

[33] Confined Animal Feeding Operations

4.3 Internal Nutrient Loads from Sediment

Sediments serve as both a source and sink for nutrients and provide the principal mechanism for internal recycling of nutrients within Big Bear Lake (see Section 2.0). Sediment samples were collected from Big Bear Lake in 2002 and 2003 and the analyses included: 1)lake sediment characteristics; 2)sediment porewater properties; and 3)sediment nutrient flux rates. The results of these investigations have been summarized in two reports (Anderson and Dyal 2003; Anderson et al. 2004). It was found that nutrient flux rates varied spatially and temporally, with greater flux rates at the west end of the lake and in the summertime. This spatial variability in flux rates is important when considering and executing lake restoration activities. For example, for the lake-wide alum project conducted during summer 2004, alum application rates were adjusted to higher doses at the west end and lower doses at the east end[34]. It was also found that there is a spatial trend of increasing silt from west (MWDL1) to east (MWDL9) (Table 4-3). Similarly, data collected as part of the TMDL monitoring shows a spatial trend of increasing particulate phosphorus from west to east (Table 4-4).

Table 4-3. Sediment Characteristics of Big Bear Lake

Station	Sand (%)	Silt (%)	Clay (%)
MWDL1	79.3	7.3	13.4
MWDL2	72.8	14.1	13
MWDL6	73.5	16.2	10.3
MWDL9	57.4	30.5	12.1

Data Source: Modified from Anderson and Dyal (2003)

Table 4-4. Percentages of Dissolved Phosphorus (DP) and Particulate Phosphorus (PP) (2001-2003)

	Averages	
Station	DP%	PP%
MWDL1	46%	54%
MWDL2	46%	54%
MWDL6	41%	59%
MWDL9	34%	66%

As explained in Section 4.1, most of the sediment-related inputs to the lake occur during wet weather events and the highest loads come from granitic sands in forested areas. It is hypothesized that the apatite fraction of the granitic sands weathers within the lake and becomes bioavailable to the plants over time (BBMWD, Hydmet, Inc., and AquaTer, Inc. 2003). However, an alternative hypothesis is that the mineralization[35] of organic matter in the lake sediments occurs at a much faster rate than the weathering process, so that the process of mineralization has more effect on the diffusive flux of

[34] The application of aluminum sulfate (alum) to lakes is used to remove phosphorus from the water column (phosphorus precipitation), as well as to prevent phosphorus release from the sediments (phosphorus inactivation). Application of alum to lakes has been successful in decreasing total phosphorus concentrations and restoring beneficial uses.

[35] Mineralization is the conversion of organic forms into mineral or inorganic forms

nutrients from lake bottom sediments than does weathering (Tetra Tech 2004a). If apatite is not a source of readily bioavailable phosphorus for macrophyte uptake, then the total phosphorus load estimated by the HSPF model during extreme wet events (i.e., 1993) might consist of a majority of phosphorus that will only become bioavailable in the lake over the long-term. According to Anderson and Dyal (2003), soluble reactive phosphorus (SRP) fluxes occurred from mineralization or release from surficial material, not from material deeper in the sediments. Therefore, the 10 cm sediment cores collected in November 2003 are likely the best representation of sediment-phosphorus fractions that are important to the internal loading of phosphorus and to the growth of macrophytes within the lake. Data from these sediment cores were used to identify the fractions of phosphorus in the sediment for alum dosage considerations. The bioavailable forms of phosphorus are the loosely-bound P (i.e., $CaCO_3$-P and loosely sorbed P) and the iron-bound P fractions. The forms of phosphorus not easily transformed for uptake by biota are the aluminum-bound P and the calcium-bound (i.e., apatite) fractions. Residual-P is calculated by subtracting the various fractions from total P. The November 2003 data showed the highest fraction of calcium-bound phosphorus and loosely-bound P occurred at Station MWDL9, at the east end of the lake (Figure 4-5). The highest fractions of both aluminum-bound and iron-bound P were located at Station MWDL1. Sediment core flux studies conducted in 2002 (Anderson and Dyal 2003) and 2003 (Anderson et al. 2004) measured the highest flux rates of SRP at Stations MWDL1 and MWDL2 at the west end of the lake, and the lowest at the east end (Station MWDL9). From these data, it appears that iron-bound P drives the internal loading of phosphorus at the west end, while the loosely-bound P provides a readily bioavailable source of phosphorus for the macrophytes at the east end.

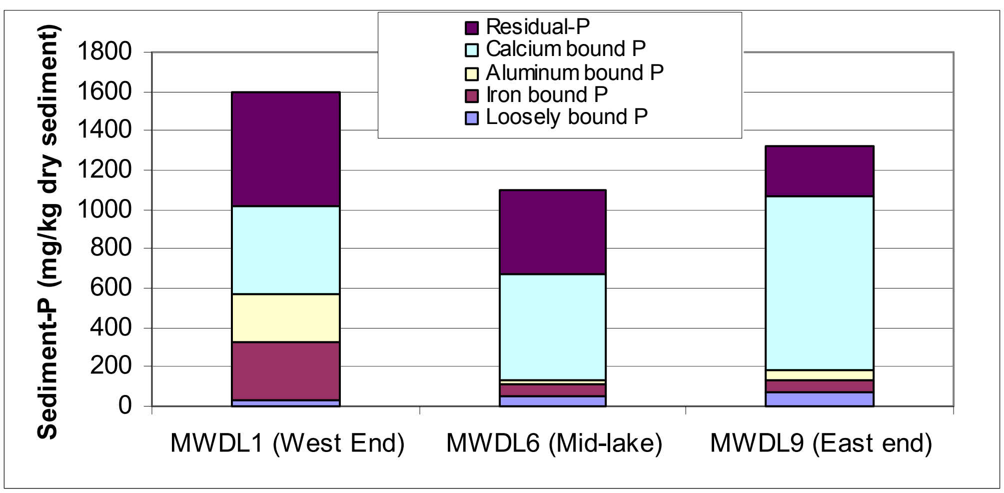


Figure 4-5: Average sediment-phosphorus fractionation for four types of sediment sources to Big Bear Lake, 11/6/2003

Tetra Tech (2004a) derived time functions to represent sediment fluxes as a function of either time of year or lake bottom depth for the WASP model. This enabled the proper characterization of sediments as a source of nutrients to the water column. Shown in Table 4-5 are sediment loads derived for each segment area for the period of record 1999-2003. These loads were derived by Tetra Tech (2004a) based on the work by Anderson and Dyal 2003 and Anderson et al. 2004. Anderson and Dyal (2003) and Anderson et al. (2004) provided seasonally-averaged nutrient loads for 6 months based on flux rates measured in summer-fall 2002 and 2003 and areas within each sediment depth zone[36].

Because of anoxic conditions at the sediment-water interface, the dominant form of nitrogen released from sediment is ammonium nitrogen (NH_4-N). The total loads for the 6 month summer-fall period in 2002 and 2003 were 105,311 lbs NH_4-N and 17,585 lbs soluble reactive phosphorus (SRP). Based on data collected by Anderson in 2003 to determine winter flux rates, staff estimated that during the remaining six-month period, the sediment nutrient flux is approximately 50% of the summer-fall NH_4-N load and 11% of the summer-fall SRP load. Based on these data, staff estimated total annual loads from sediment at 158,027 lbs NH_4-N and 19,436 lbs SRP. These loads are similar to the loads determined by Tetra Tech (2004a) (Table 4-5). Tetra Tech did not use the October 2003 sediment flux rates in their modeling effort because these rates were much higher in 2003 than in 2002 and could not be explained (Anderson et al., 2004)[37]. Because of the variation in flux rates from year-to-year, use of the average nutrient sediment loads over a 5-yr period as shown in Table 4-5 is appropriate for the nutrient budget. These values are 152,386 lbs NH4-N and 21,388 lbs SRP.

In addition to internal releases of nutrients, resuspension and sedimentation are important processes affecting in-lake nutrient concentrations. However, because of the complexity of these processes, sedimentation and resuspension of nutrients were not measured. Sedimentation[38] is the primary process affecting nutrient availability within Big Bear Lake during dry years, since watershed inputs of nutrients are minimal (Tetra Tech 2004a) (see Table 4-4). Model simulation of these processes indicates net settling velocities on the order of 75-102 m/yr depending on the constituent (Tetra Tech 2004a). These processes should be measured and the results included in any future modeling effort.

[36] Five sediment zones (e.g., A = depths > 33.6 feet) within the lake were defined by depth based on the location of the sediment sampling stations for the flux studies.

[37] Many restoration activities were initiated and carried out at the same time as sampling efforts continued for model development. These included the application of the herbicide Sonar and alum. For this reason, many anomalies in the sediment and water quality data cannot be explained. Variations in data could be due to lake level decreases, application of an aquatic herbicide, die-off of macrophytes, alum application or normal lake processes. More importance was placed on data acquired in 2001 and 2002, rather than 2003 when the effects of all ongoing restoration activities would have been maximized. Measurement of nutrient release rates from sediment continued in 2004 and 2005 and will continue as part of the TMDL implementation plan in order to determine the effectiveness of lake restoration projects designed to lower internal nutrient loads.

[38] Sedimentation is the deposition or settling of suspended material (both organic and inorganic) in water.

Table 4-5. Nutrient loads from sediment

SRP LOAD (LBS)

	Dam	Open Water 1	Boulder Bay	Open Water 2	Metcalf Bay	Open Water 3	Grout Bay	Open Water 4	Main Bay	East End	Total
5-yr P load	851	16006	2403	25435	3601	19624	1217	16332	10927	10543	106938
Average per year	170	3201	481	5087	720	3925	243	3266	2185	2109	**21388**
% OF TOTAL AVG. LOAD PER YEAR	1%	15%	2%	24%	3%	18%	1%	15%	10%	10%	
1999	181	3309	544	5238	944	4088	417	3400	2421	2565	23107
2000	176	3266	524	5189	853	4042	357	3349	2367	2452	22575
2001	171	3218	501	5123	751	3974	275	3290	2276	2260	21838
2002	163	3125	435	4974	557	3800	107	3170	2000	1736	20067
2003	160	3089	399	4910	495	3720	61	3122	1863	1531	19351

AMMONIUM-NITROGEN LOAD (LBS)

	Dam	Open Water 1	Boulder Bay	Open Water 2	Metcalf Bay	Open Water 3	Grout Bay	Open Water 4	Main Bay	East End	Total
5-yr N load	6147	115876	20492	175311	28347	123964	16671	97704	84711	92709	761932
Average per year	1229	23175	4098	35062	5669	24793	3334	19541	16942	18542	**152386**
% OF TOTAL AVG. LOAD PER YEAR	1%	15%	3%	23%	4%	16%	2%	13%	11%	12%	
1999	1309	23946	4646	36094	7435	25819	5707	20332	18772	22561	166622
2000	1271	23657	4472	35787	6697	25547	4867	20044	18354	21536	162233
2001	1233	23280	4267	35289	5891	25085	3722	19670	17614	19796	155847
2002	1177	22635	3717	34306	4430	24027	1535	18982	15547	15381	141736
2003	1157	22358	3391	33835	3895	23488	840	18675	14423	13433	135494

Data source: Analysis and summary prepared by Tetra Tech, 2004a with data supplied by Anderson and Dyal (2003) and Anderson et al. 2004

4.4 Internal Nutrient Loads from Macrophytes

Aquatic macrophytes are both sources and sinks of nutrients. During fall, when macrophytes die-off and decay, nutrients are released back into the water column and to the sediment through macrophyte decomposition[39]. At other times, macrophytes obtain nutrients from the water column and/or from the sediment, depending on the species. This process can reduce the amount of nutrients in the water column that would be available for planktonic algae growth.

Plant biomass and plant tissue nutrient concentrations were measured to estimate the contribution of aquatic macrophytes to the internal nutrient load. Plant tissue samples were collected on two occasions in 2002 and analyzed for nitrogen and phosphorus content. Biomass samples were obtained in 2002 and 2003. Samples were collected from areas that had not received treatment with the aquatic herbicide, Sonar PR. Plant tissue collection efforts and locations are described in BBMWD, Hydmet, Inc, and AquAeTer, Inc. (2003). Locations of plant biomass stations as well as the plant biomass data collection methodology are described in BBMWD and ReMetrix (2004). The results of all the vegetation assessments performed by ReMetrix from 2002-2003 were used by Tetra Tech (2004a), with some additional manipulation, for input into the WASP lake model. Due to the way in which the biomass samples were collected, it was postulated by Tetra Tech that the actual biomass was higher than that measured; thus, Tetra Tech (2004a) used three times the average calculated volumetric density in their calculations[40]. These numbers should be refined with future macrophyte assessments.

Shown in Table 4-6 are the total macrophyte biomass and total macrophyte nitrogen and total macrophyte phosphorus nutrient standing stocks in Big Bear Lake as calculated by Tetra Tech (2004a). As shown in Table 4-6, macrophytes represent a significant source and sink of nutrients in Big Bear Lake.

Table 4-6. Total estimated peak annual macrophyte biomass and nutrient standing stocks (Tetra Tech, 2004a)

Year	Total Macrophyte Biomass (lbs)	Total Macrophyte Nitrogen* (lbs)	Total Macrophyte Phosphorus* (lbs)
1999	4,885,996	92,345	14,169
2000	5,989,631	113,205	17,371
2001	6,698,234	126,596	19,424
2002	6,754,230	127,654	19,587
2003	6,608,905	124,909	19,166
Average	**6,187,399**	**116,942**	**17,943**

*based on plant tissue measurements (BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003)

[39] These releases of nutrients are mitigated by uptake by epiphytic bacteria and algae (Wetzel 2001, 546). Similarly, macrophytes act as large reservoirs of nitrogen and phosphorus, immobilizing the nutrients into tissues (Wetzel 2001, 215, 254).

[40] Plant biomass samples were calculated by the rake method. However, this method might have underestimated the true biomass of samples, especially with respect to the free-floating macrophyte, coontail, which might not be captured by the rake. Calculated volumetric density ranged from 287.1 to 5414 g/m^3, with an average of 1571 g/m^3. Three times this average, or 4713 g/m^3, was used in the WASP model. Two macrophyte biomass control samples obtained prior to the 2002 Sonar treatment had densities that were above the calculated average (2029 and 3885 g/m^3). For discussion on the macrophyte modeling, please see Tetra Tech (2004a).

4.5 Summary of Nutrient Loads from All Sources

Table 4-7 summarizes the sources and the corresponding annual average loads for the dry period 1999 to 2003 for HSPF-simulated watershed sources, atmospheric deposition, sediment and macrophyte sources to Big Bear Lake. This information is also shown graphically in Figures 4-6 and 4-7. Sedimentation and resuspension of nutrients were not determined for this nutrient budget, although in the future they should be measured and incorporated into the nutrient budget.

Also shown in Table 4-7 are the total loads under an extreme wet event (1993), and the annual average loads for the period 1990-2003, which incorporates all types of hydrological scenarios. These loads are shown for comparison purposes only. Note that macrophyte and sediment loads are constant for all these scenarios because there are no relevant data for extreme wet or average hydrological events.

As shown in Figures 4-6 and 4-7, for the dry period 1999-2003, the average nutrient loads from the sediment and macrophytes is approximately 91% of the total nitrogen load and 96% of the total phosphorus load. As can be expected, external nutrient loads are the driving force for total phosphorus loading to Big Bear Lake during a wet year, providing approximately 71% of the total phosphorus loads. Total nitrogen loads contributed from internal sediment and macrophyte loads during a wet year are still the primary source of nitrogen to the lake (64%). During average hydrological events, internal nutrient loads dominate, contributing 86% of the total nitrogen loads and 78% of the total phosphorus loads to the lake.

In all modeled scenarios, atmospheric deposition contributes less than 3% of the total phosphorus load and less than 8% of the total nitrogen load. As stated previously (Section 4.2), these values need to be compared to empirical data because the San Bernardino Mountains have some of the highest nitrogen loading rates in the country.

Macrophytes contribute a significant percentage of the total nutrient load (40% of TN load and 44% of TP load on average) during dry conditions, and are expected to remain a significant source of nutrients. As discussed in Section 3.1.2, staff assumes that a diverse community of macrophytes is necessary to maintain a balanced aquatic ecosystem. As such, it is expected that there will always be seasonal die-off of macrophytes, resulting in the release of nutrients to the water column or to the bottom sediments.

Table 4-7. Total nutrient loads to Big Bear Lake from all sources (lbs/year) (CY)

Parameter	Atmospheric Load[1]	Forest Nonpoint Source Load[2]	Resort NPS Load[3]	Urban Point Source Load[4]	Macrophyte Internal Load[5]	Sediment Internal Load[6]	Total Measured Load[7]
DRY SCENARIO 1999-2003 AVERAGE							
TOTAL NITROGEN	21,474	460	811	3,445	116,942	152,386	**295,518**
% OF TOTAL	7.3%	0.2%	0.3%	1.2%	39.6%	51.6%	100.0%
TOTAL PHOSPHORUS	1,074	175	33	475	17,943	21,388	**41,088**
% OF TOTAL	2.6%	0.4%	0.1%	1.2%	43.7%	52.1%	100.0%
AVERAGE SCENARIO 1990-2003 AVERAGE							
TOTAL NITROGEN	22,184	3911	5,204	12,572	116,942	152,386	313,199
% OF TOTAL	7.1%	1.2%	1.7%	4.0%	37.3%	48.7%	100.0%
TOTAL PHOSPHORUS	1,109	5,425	503	3,848	17,943	21,388	50,181
% OF TOTAL	2.2%	10.7%	1.0%	7.7%	35.8%	42.6%	100.0%
WET SCENARIO (1993)							
TOTAL NITROGEN	24,149	25,478	31,504	73,764	116,942	152,386	424,223
% OF TOTAL	5.7%	6.0%	7.4%	17.4%	27.6%	35.9%	100.0%
TOTAL PHOSPHORUS	1,207	60,325	5,057	32,628	17,943	21,388	138,548
% OF TOTAL	0.9%	43.5%	3.6%	23.5%	13.0%	15.4%	100.0%

[1] Atmospheric loads calculated for each year adjusting for lake areas; average of 1990-2003 loads used for average scenario; 1993 loads used for wet event; average of 1999-2003 used for dry event

[2] Forest nonpoint source load = HSPF simulated loads from Forest North and Forest South land uses; average of 1990-2003 loads used for average scenario; 1993 loads used for wet event; average of 1999-2003 loads used for dry event

[3] Resort nonpoint source load = HSPF simulated loads from Resort land uses; average of 1990-2003 loads used for average scenario; 1993 loads used for wet event; average of 1999-2003 loads used for dry event

[4] External point source load = HSPF simulated loads from residential and high density urban land uses; average of 1990-2003 loads used for average scenario; 1993 loads used for wet event; average of 1999-2003 loads used for dry event

[5] Macrophyte internal loads developed from data collected by BBMWD, Hydmet, Inc., and AquAeTer, Inc. 2003; ReMetrix 2004; and analyzed and interpreted by Tetra Tech 2004a

[6] Sediment internal loads developed from data collected by Anderson and Dyal 2003; Anderson et al. 2004 and analyzed and interpreted by Tetra Tech 2004a

[7] Total measured load = sum of items 1-6

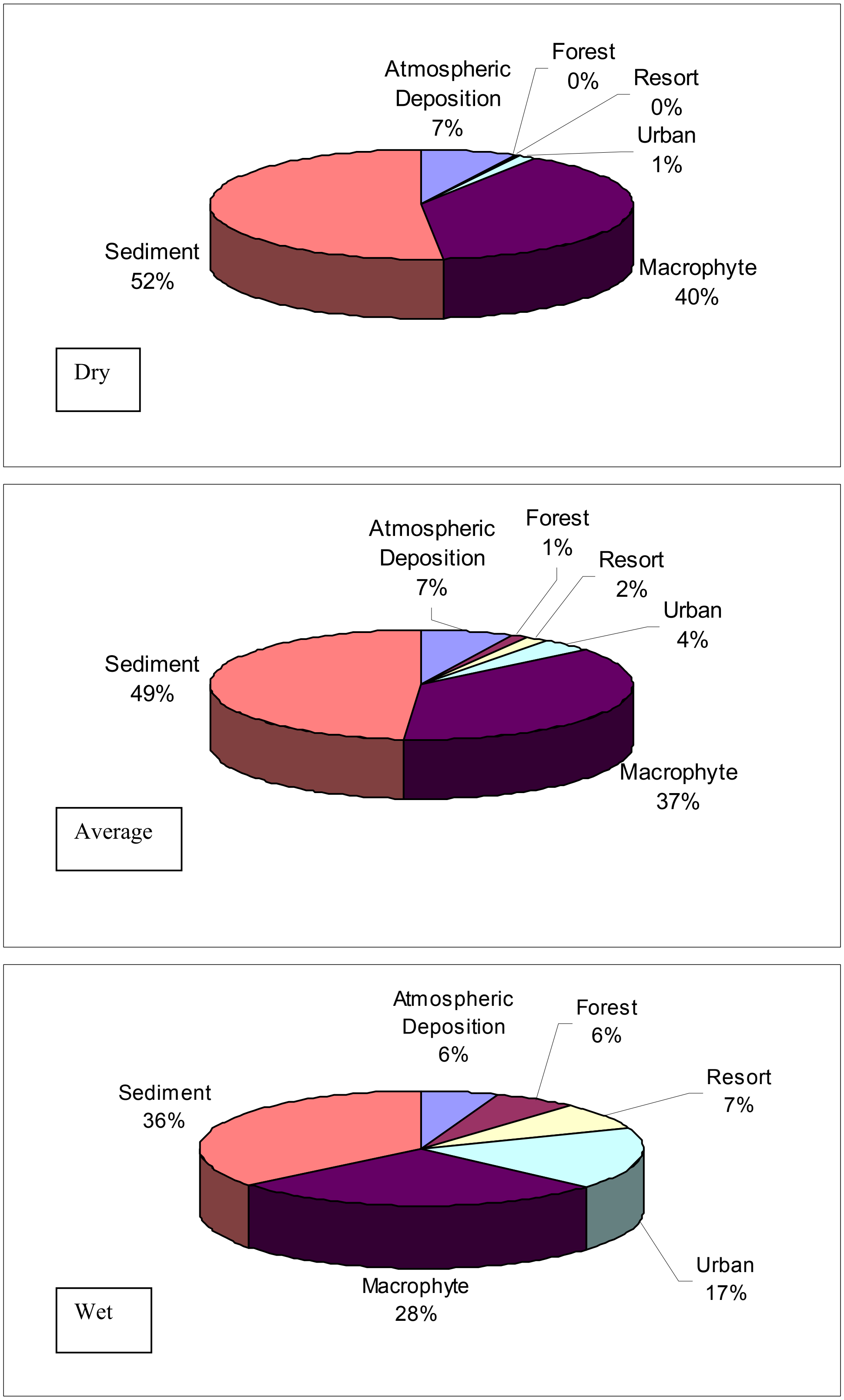
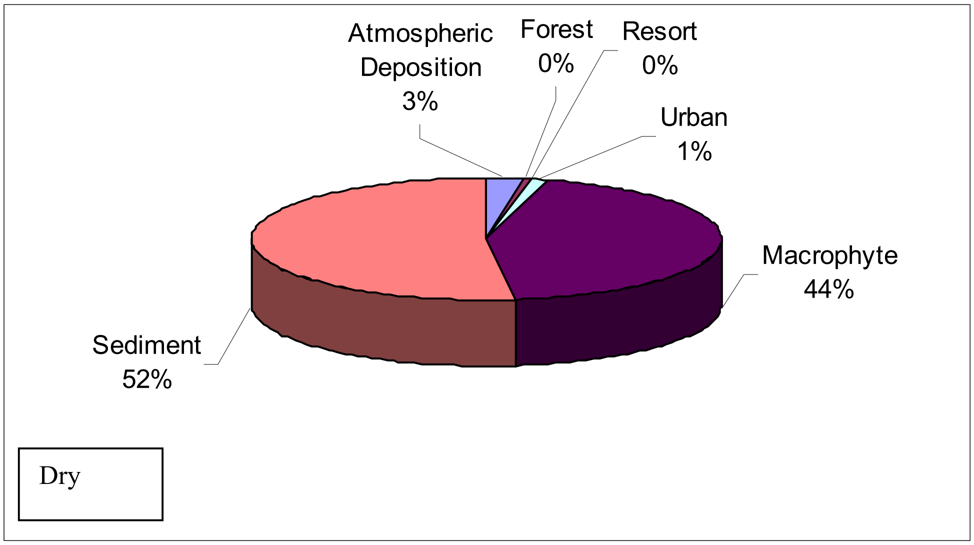
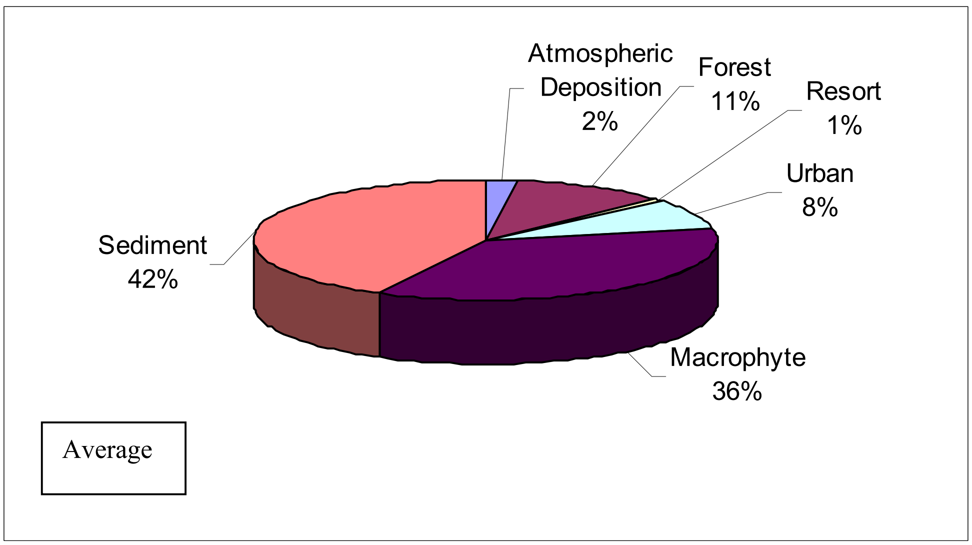


Figure 4-6. Total nitrogen load to Big Bear Lake under three conditions: dry year-average of years 1999-2003; average of years 1990-2003; wet year (1993)





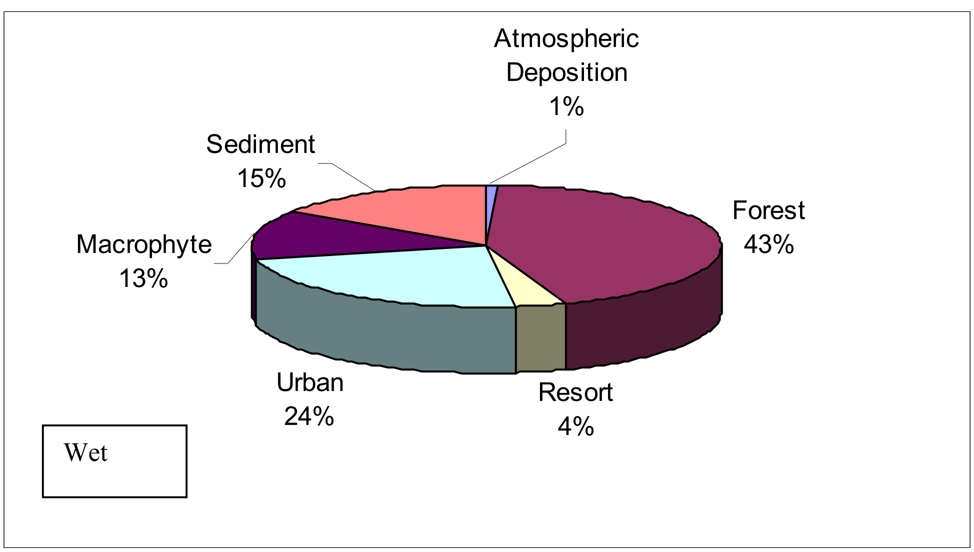


Figure 4-7. Total phosphorus load to Big Bear Lake under three conditions: dry year-average of years 1999-2003; average of years 1990-2003; wet year (1993)